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Nuclear Safeguards and Nondestructive Assay

LA-UR-21-

Alexis Trahan

June 30, 2021

Nonproliferation and Safeguards Overview
(From the INITIAL Module)

Global Nuclear Nonproliferation and Arms Control

GOAL: Prevent nuclear weapon proliferation

decrease number of states/non-state actors attempting to possess nuclear weapons

decrease capabilities of existing nuclear states

What can we do?

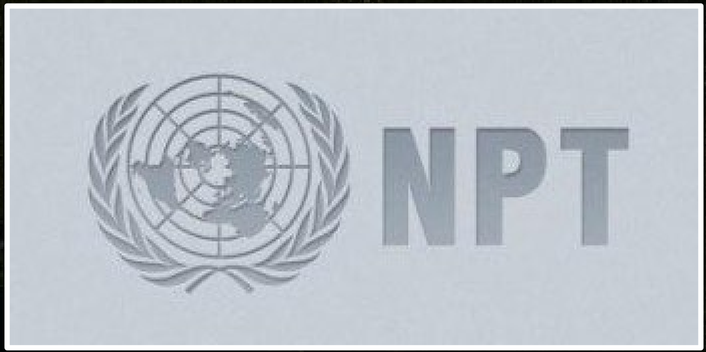
- Encourage/ensure peaceful nuclear uses
- Secure, safeguard, and/or dispose of dangerous nuclear and radiological material
- Detect and control the proliferation of related WMD technology and expertise

Nuclear Test at the Mururoa atoll, French Polynesia (courtesy *The Atlantic*)

How These Goals Are Achieved

- Nuclear Non-Proliferation Treaty (NPT)
  - ⟶ Bans acquisition of nuclear weapons by non-weapon states
- Comprehensive Test Ban Treaty
  - ⟶ Bans nuclear explosions
- Fissile Material (Cutoff) Treaty
  - ⟶ Would ban fissile material production

Note: Verification is the key element

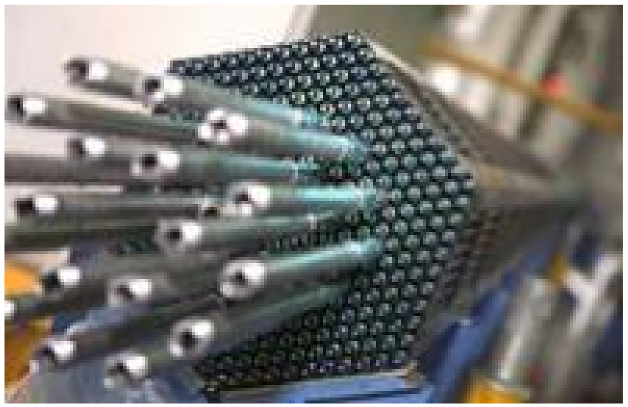


Science and technology play a vital role

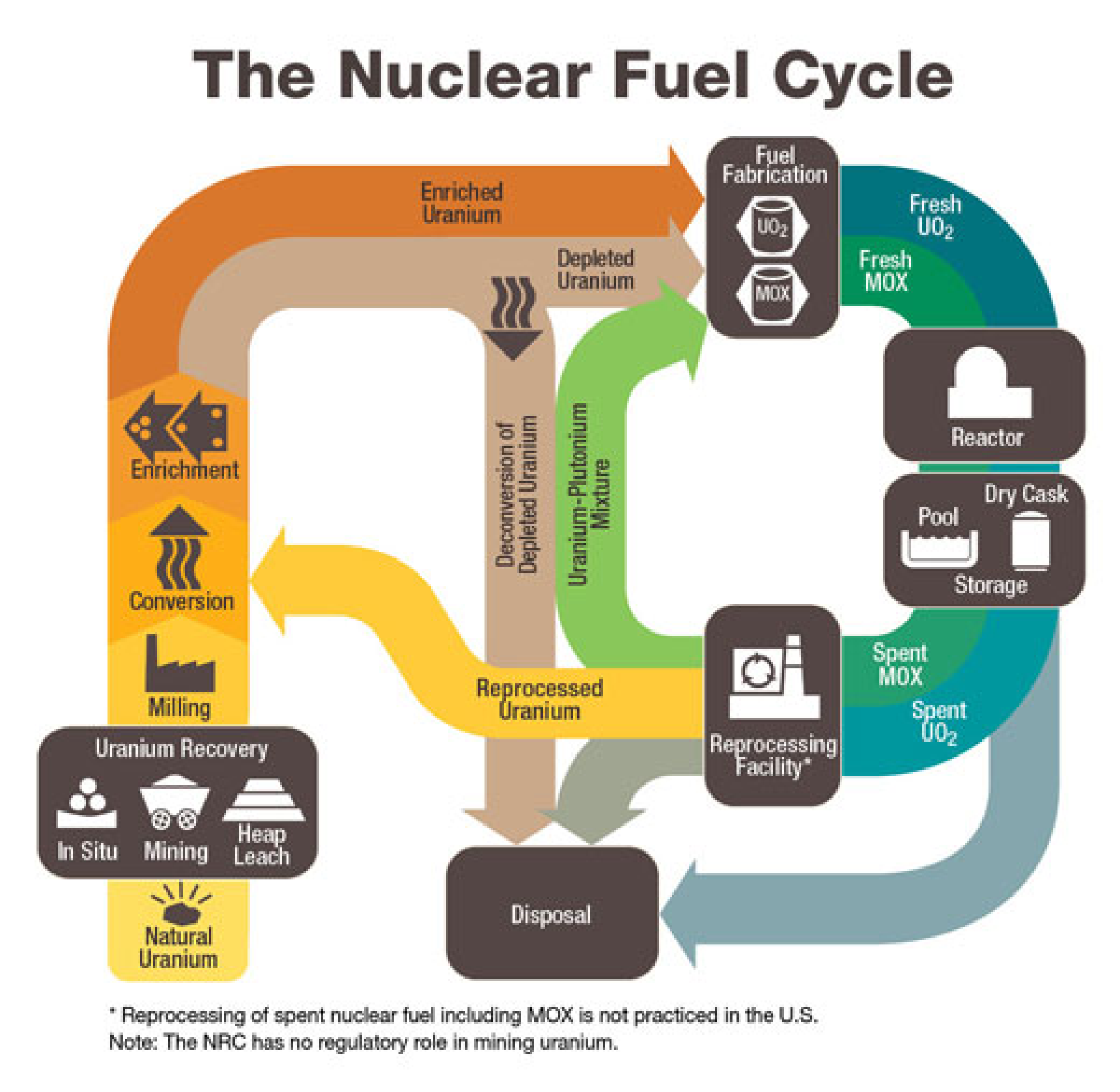
Fissile Material Production

- Cost and Time make producing **Significant Quantities (SQ)** of nuclear material is the most difficult step to production of nuclear weapons
- Historically, Special Nuclear Material production for proliferation purposes has been achieved via:
  - Enrichment of uranium
  - Reprocessing of plutonium from spent fuel

Nuclear Material	SQ
Plutonium (<80% Pu-238)	8 kg Pu
Uranium-233	8 kg U-23
HEU (≥20% U-235)	25 kg U-235
LEU (<20% U-235)	75 kg U-235
Natural/Depleted U	10 tons/20 tons
Thorium	20 tons



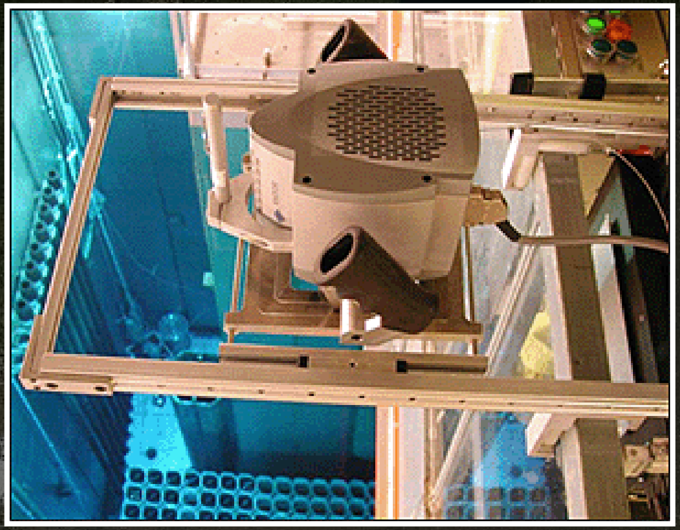
The Nuclear Fuel Cycle



Source: NRC.gov

International Safeguards

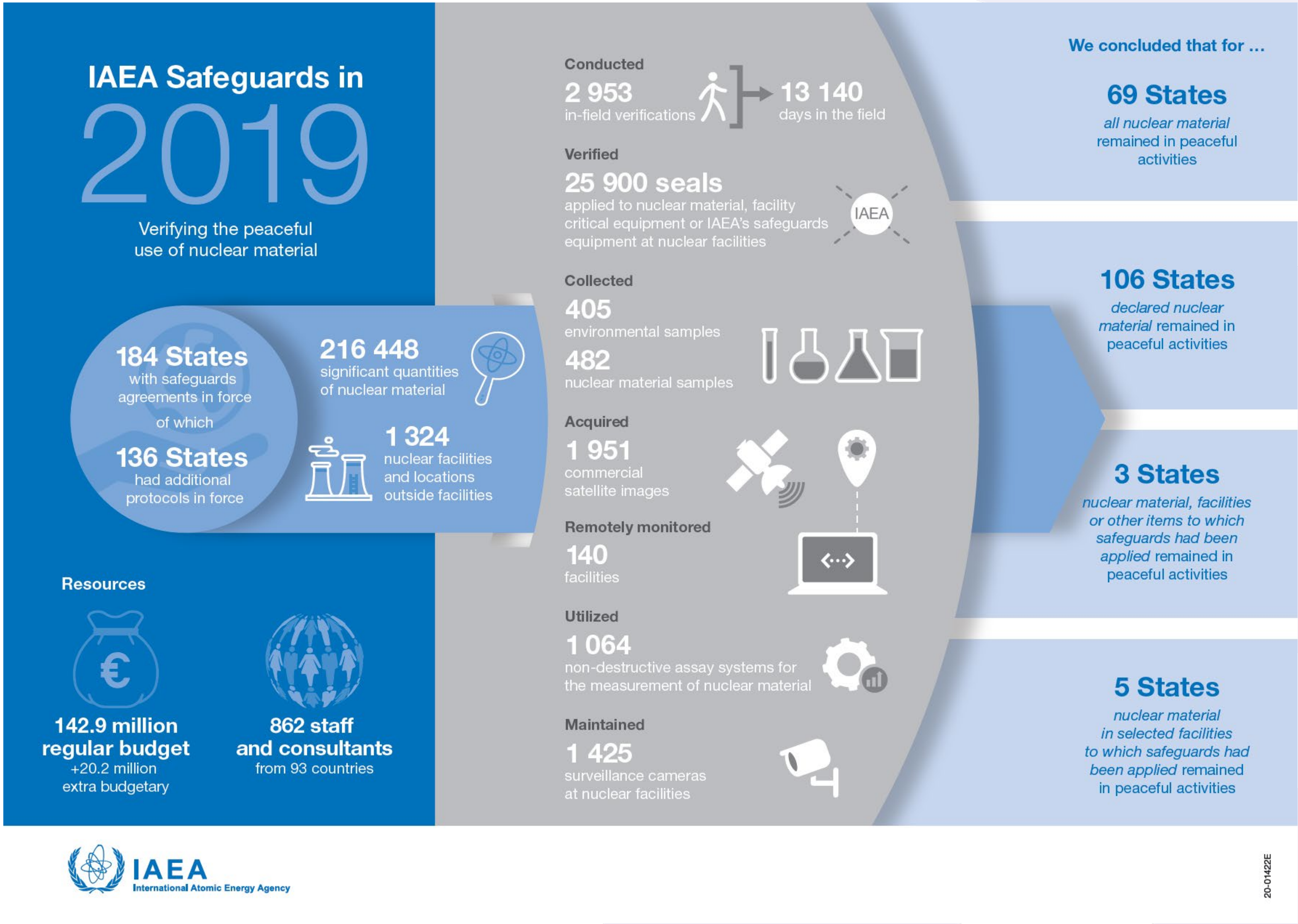
- "Delivering Effective Nuclear Verification for World Peace"
- The objective of **safeguards** is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons
- Inspect nuclear facilities worldwide, monitor amounts of nuclear materials to ensure that it isn't going to illicit uses
- Work conducted under Comprehensive Safeguards Agreements



Source(s): www-pub.iaea.org/MTCD/Publications/PDF/nvs1_web.pdf

International Atomic Energy Agency and LANL

The International Atomic Energy Agency



The International Atomic Energy Agency

- Currently, the IAEA is working to advance the following initiatives (among many others...)
  - Universal acceptance of the Additional Protocol
  - Safeguards-by-design
    - Integrated within a facility's design, covering safeguards and security
  - Unattended monitoring & data integration
    - Robust data management systems to reduce on-site inspector presence
  - State-level Concept
    - Assessing each State as a whole
    - Developing unified and consistent State-Level Approaches
    - Establishing safeguards measures based on path attractiveness rather than simply material attractiveness

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LANL Support

Over 50 years of support for the IAEA through…

Technology development

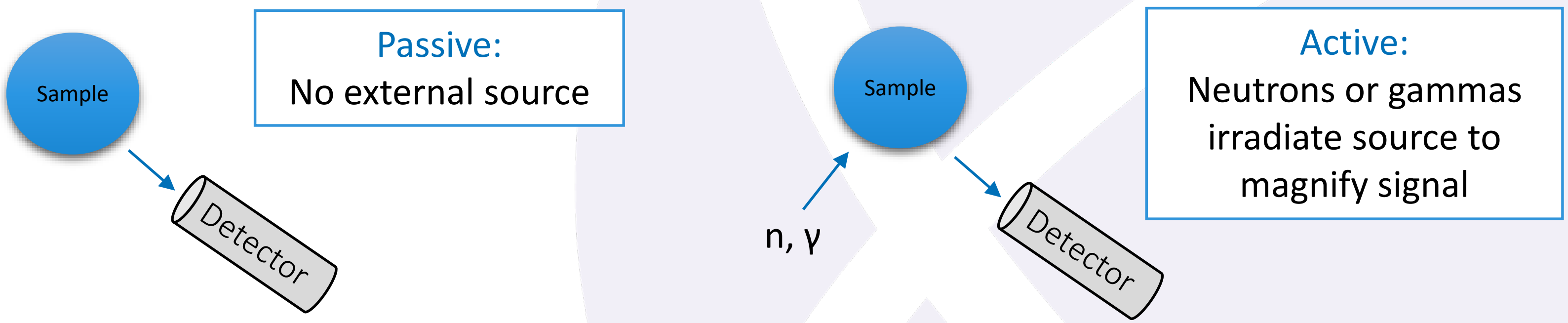
Training

Expertise

Nondestructive Assay

Nondestructive Assay

- NDA is the most commonly employed technique for material accountancy
- A series of gamma or neutron detectors are typically used to measure radiation emitted from the sample of interest
- Energy, timing, and intensity of radiation may be correlated to isotope type and quantity in the sample



- Passive interrogation requires good signal intrinsic to sample (^{240}Pu, ^{252}Cf)
- Active interrogation requires fissile material or material prime for gamma interactions (^{235}U, ^{239}Pu)

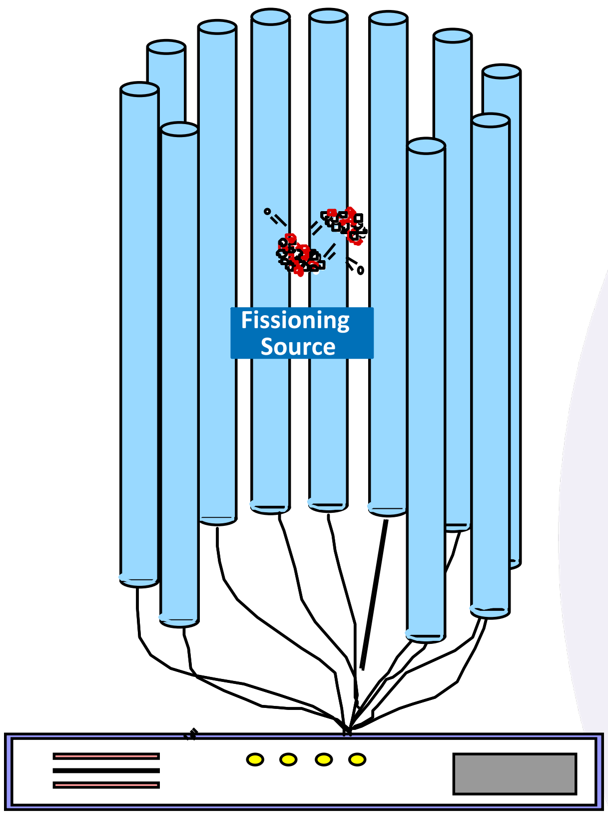
Neutrons and Photons as NDA Signatures

	Neutrons	Photons
Origins	– Spontaneous and induced fission – (α,n) – Cosmic rays – (p,n) – (n,2n) – (γ,n) Less common	– Nucleus (gamma-ray) – Nuclear collision (gamma-ray) – Electron cloud (x-ray)
Signal	Time and correlations	Energy
Shielding	Low Z material	High Z material
Detectors	^{3}He, Scintillators, fission chambers	HPGe, Scintillators, NaI, CZT, LaBr

History of Neutron Counting for NDA

- TOTAL NEUTRON
  - Record the total number of neutrons detected in a certain amount of time
  - Accurate assays can be obtained only for very few types of SNM
- COINCIDENCE COUNTING
  - Record the number of times two neutrons arrive within a set time window (gate)
  - Wide application for international safeguards
    - focused on verifying declared materials
- NEUTRON MULTIPLICITY COUNTING
  - Extension of neutron coincidence counting
  - Record the number of times we detect 2, 3, 4, etc. neutrons within a gate
  - It improves neutron assay accuracy dramatically by adding more measured information

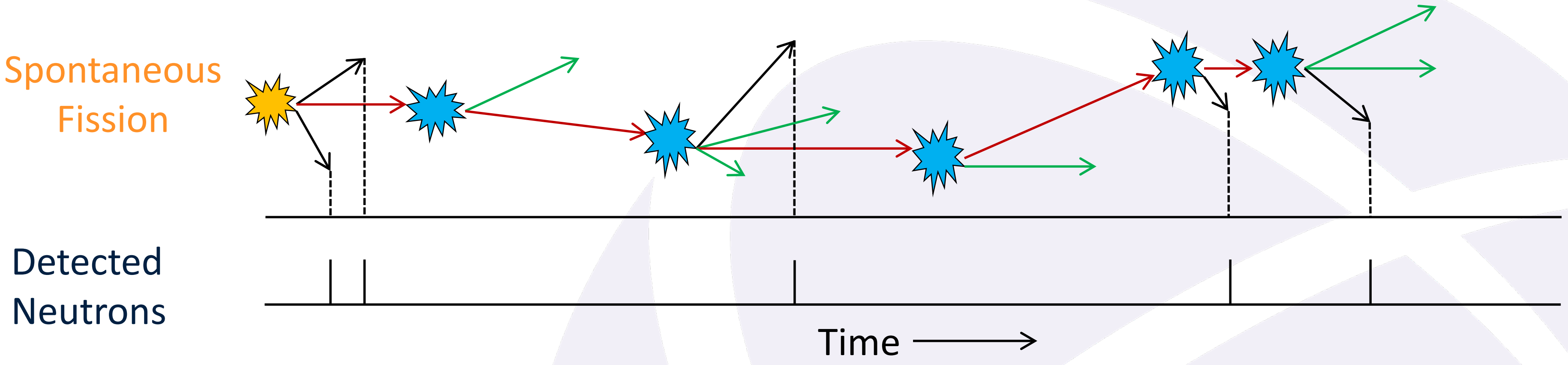
Neutron Coincidence Counter



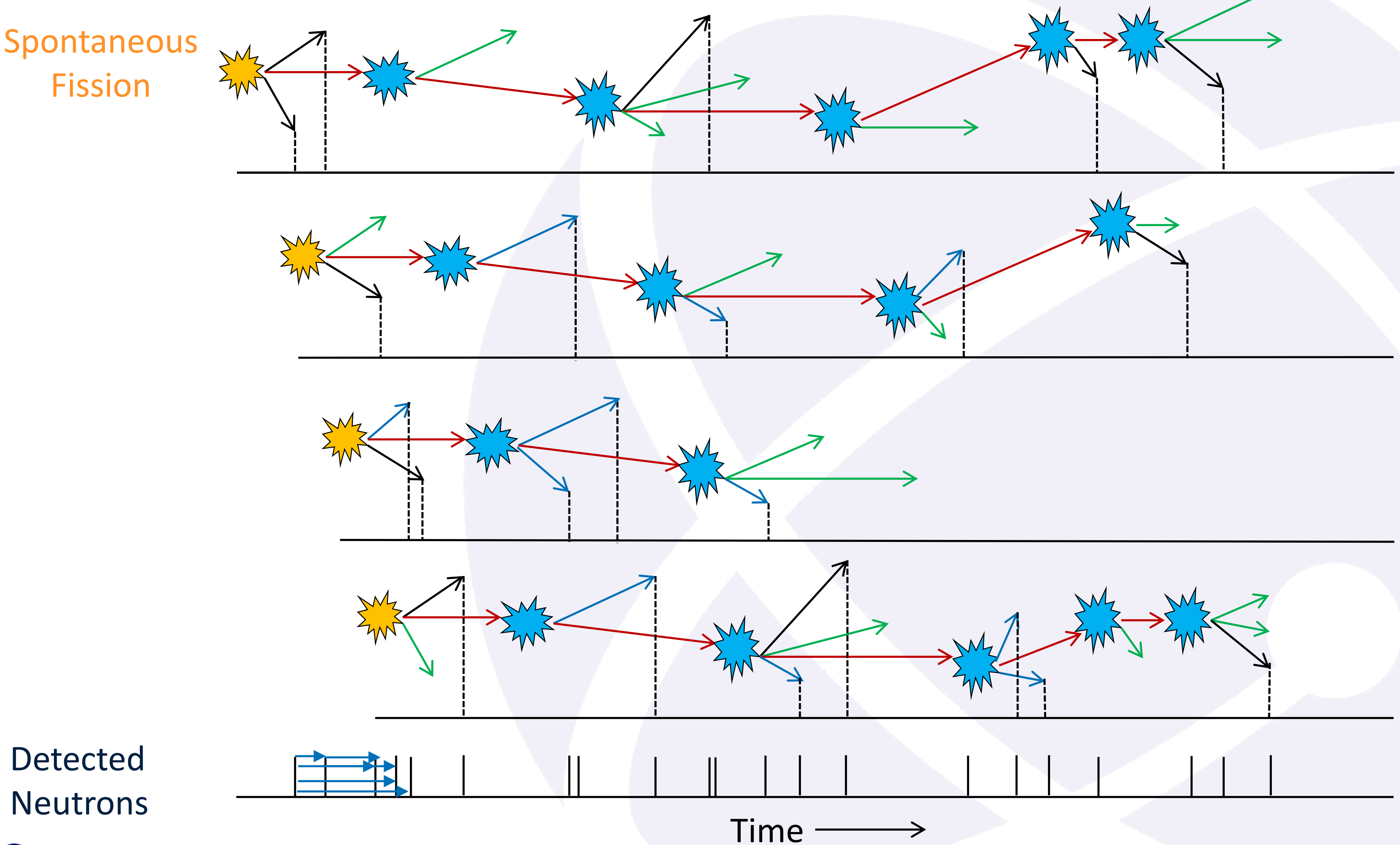
Pulse-processing Electronics

- ^3He neutron detectors
- Fission source (Pu) surrounded by neutron detectors
- Emission of multiple **prompt** neutrons from fission detected as coincident neutron events
- Multiplicity information is used to calculate the mass of fissile isotopes

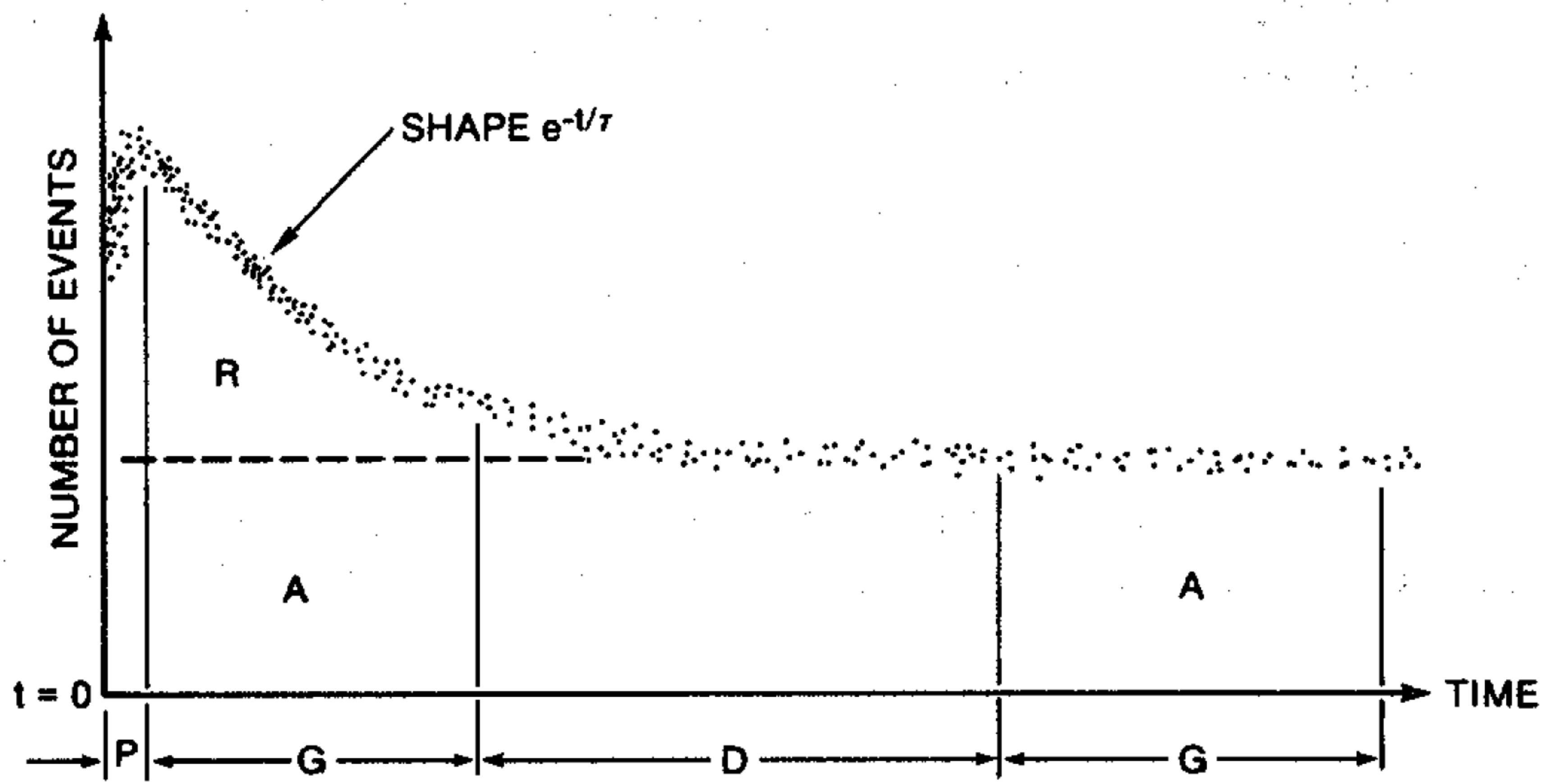
Neutron Coincidence Counting



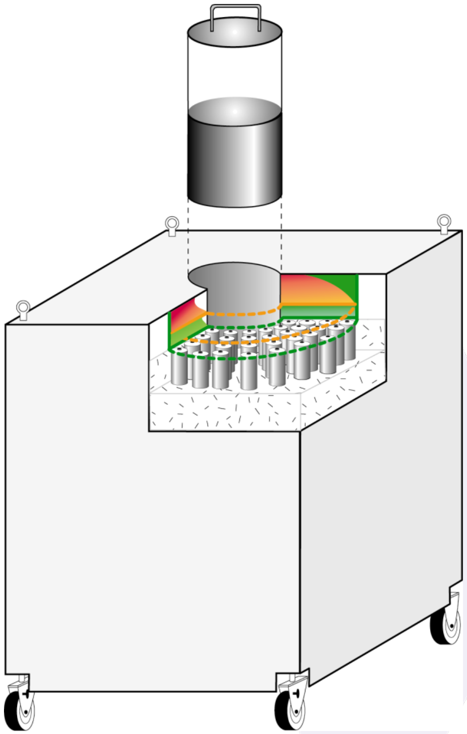
Neutron Coincidence Counting



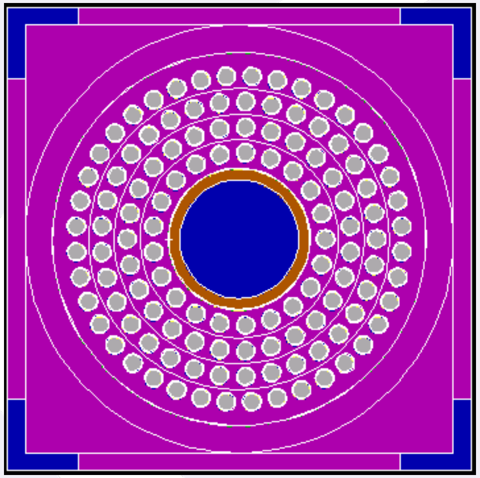
Rossi-Alpha Distribution



Epithermal Neutron Multiplicity Counter (ENMC)



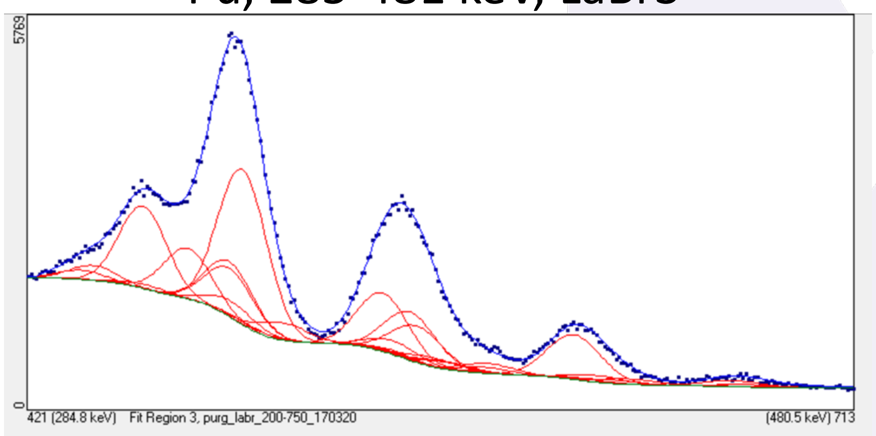
- ε = 65.0%
- τ = 22.0 μsec
- 121 tubes
- 27 preamplifier channels



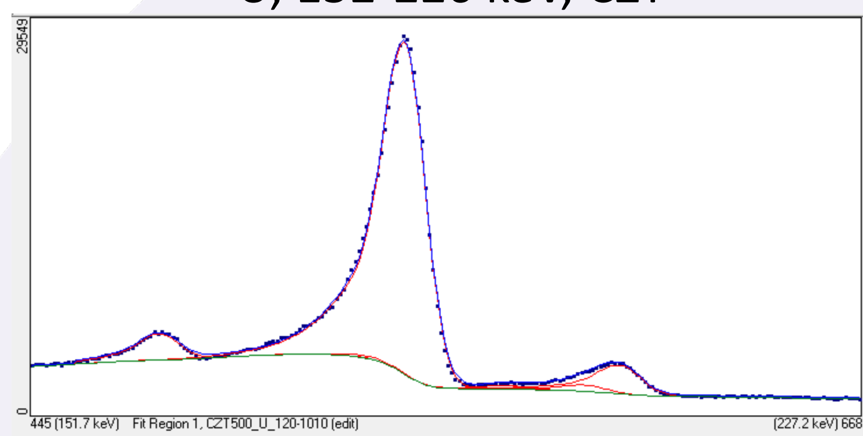
FRAM

- FRAM is an isotopic analysis code nominally designed for plutonium and uranium.
- **F**ixed-energy **R**esponse-function **A**nalysis with **M**ultiple efficiencies.
- Self-calibration using several gamma-ray peaks.
- Analyze gamma ray data from 30keV to >1MeV of HPGe, CdTe, CZT, and LaBr3 detector.

Pu, 285-481 keV, LaBr3



U, 152-226 keV, CZT



Spent Fuel Characterization

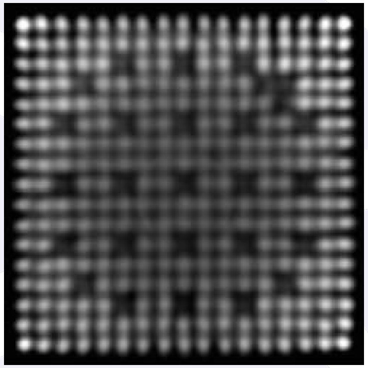
Power Reactor vs. Research Reactor

- Why are these two VERY different characterization problems?

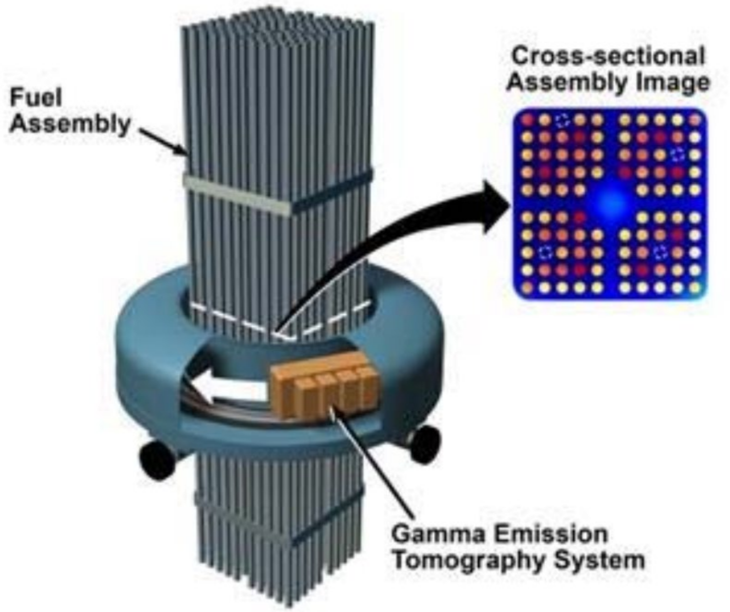
	Power	Research
Size	~4 m long, 20 cm across, 1000 lbs	~80 cm long, 8 cm across, 13 lbs
Neutrons	~1E8 1/s	~1E4 1/s
Neutron Emitters	^{242}Cm, ^{244}Cm, ^{240}Pu	^{240}Pu
Operating History	Predictable, $$$	Unpredictable, research
Easy Availability of Calibration Standards?	Nope!	Nope!

Passive Gamma Emission Tomography (PGET)

- Three simultaneous measurements: gross neutron, gamma spectroscopy, and 2D emission tomography
- Create an axial image of emission locations to detect pin-level diversions
- Measurements take 3-5 minutes



Mayorov et al., IEEE, 2017

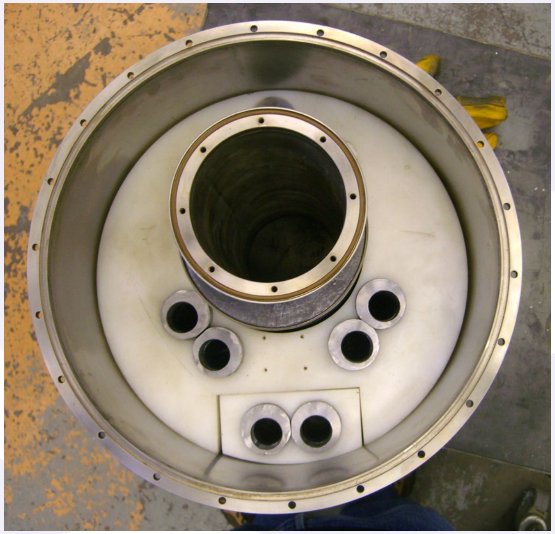


Miller et al., PNNL, 2017

- Neutron data are used for BU, spectroscopy data for CT or to verify non-fuel items
- Has been tested for burnups from 5.7-58 GWd/tU and cooling times from 1.9-27 years

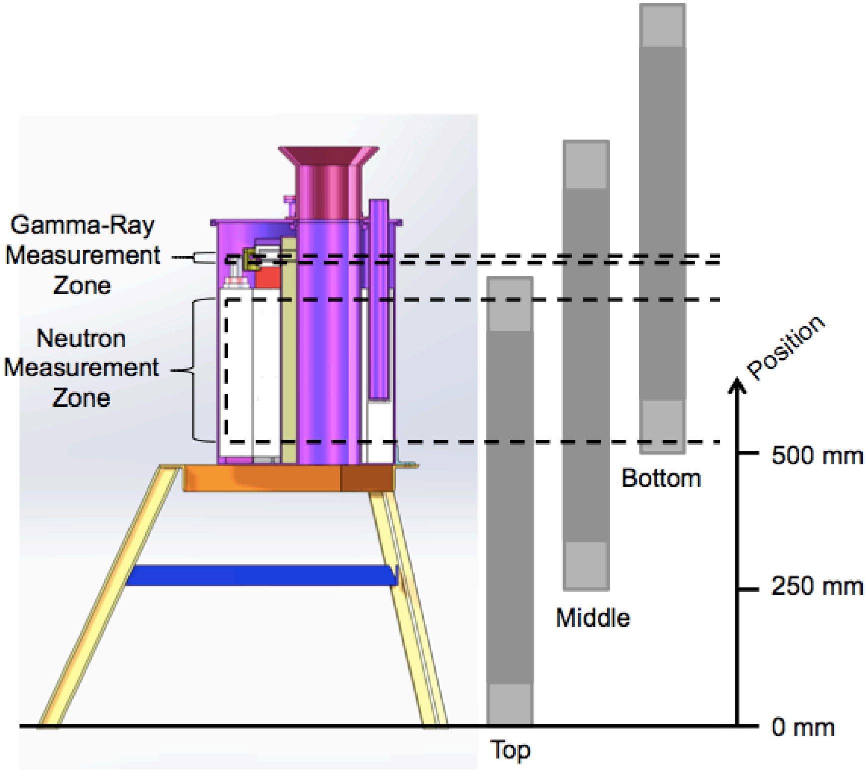
Advanced Experimental Fuel Counter

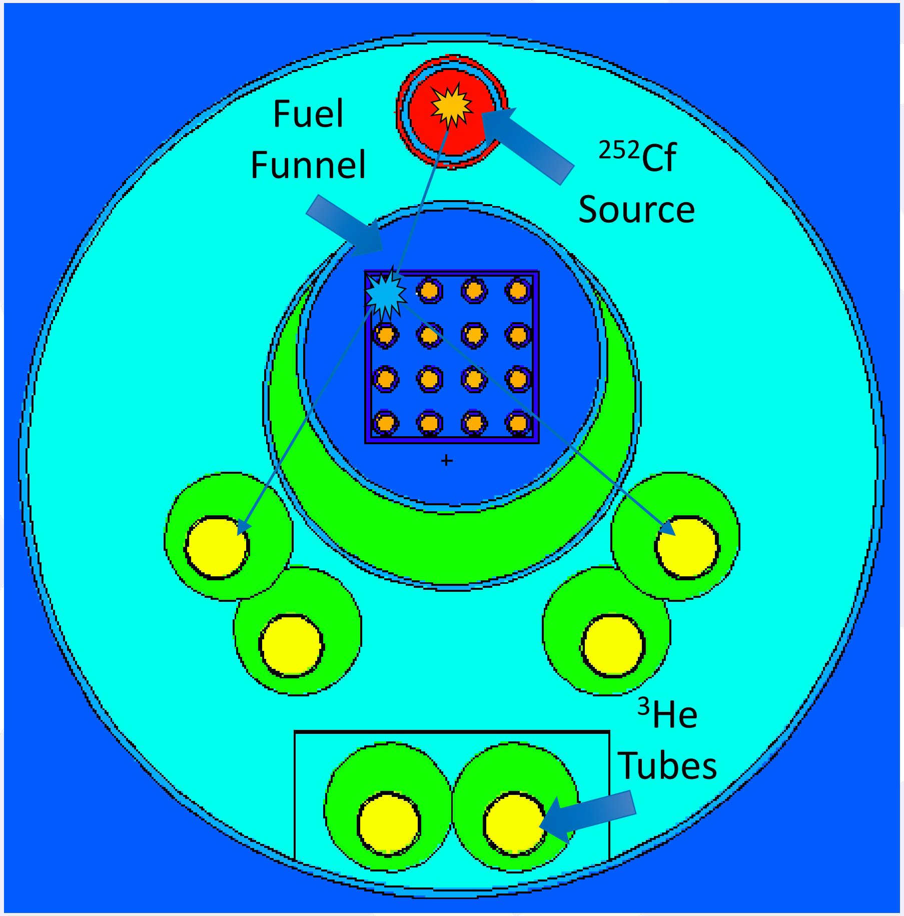
- Designed for research reactor spent fuel characterization
- System uses:
  - Active and passive neutron coincidence counting
  - An ion chamber for gross gamma-ray counting
- Measurement objective is to verify residual fissile mass (i.e., ^{235}U + ^{239}Pu) using active neutron interrogation
- Field trials have occurred as follows:
  - 2006 High Flux Australian Reactor (HIFAR), Australia
  - 2011 Institute of Nuclear Physics (INP), Uzbekistan
  - 2014 Institute of Nuclear Physics (INP), Uzbekistan
  - 2018 Soreq Nuclear Research Center (SNRC), Israel



Advanced Experimental Fuel Counter

- Measure top, middle, and bottom of assemblies with active and passive interrogation

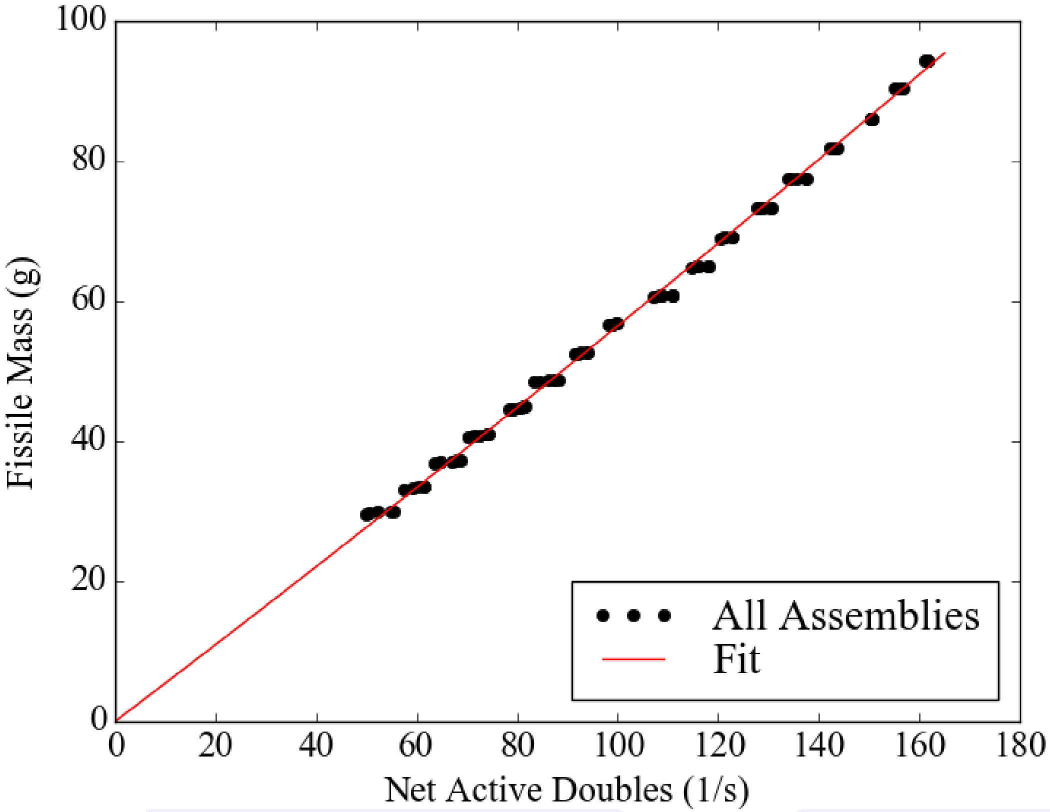




Advanced Experimental Fuel Counter

Active Doubles – Passive Doubles – Cf Doubles = Net Active Doubles

- Net active doubles rate is proportional to residual fissile mass
- But it can vary! Control rod insertion, operating history, assembly rotation, cooling time, can all affect the doubles rate relative to the fissile mass



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Thank you!

Questions?